US Energy Department Solar Energy Technologies Office, CSP

Gen3 Gas Phase System Development and Demonstration

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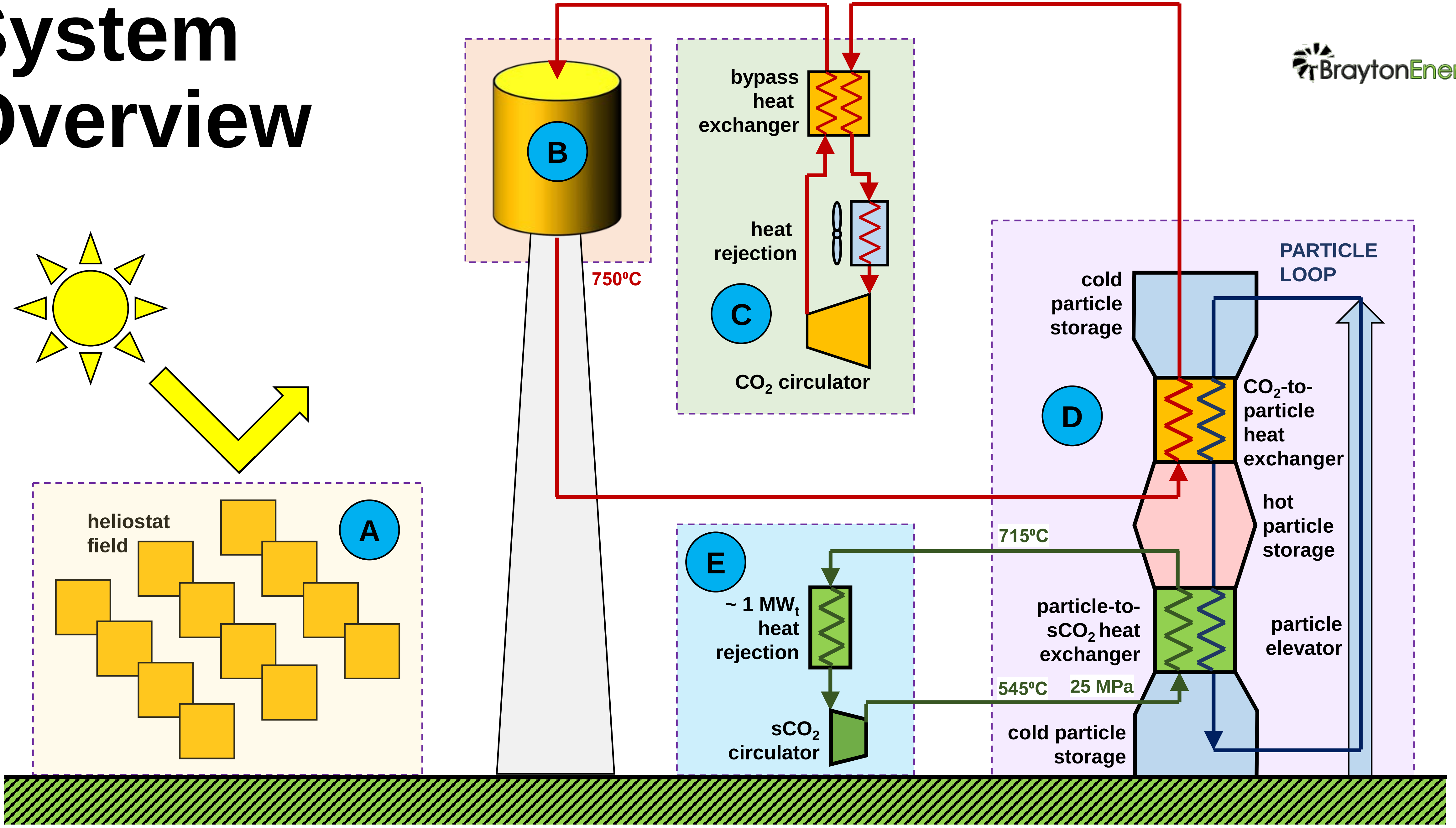
25 June 2018
DOE Concentrating Solar Power Gen3 Kickoff
Disney Contemporary Resort
4600 N World Dr
Orlando, FL 32830

Agenda

- Overview
- Major Subsystems
  - Heliostat Field
  - Receiver
  - Circulator System
  - Thermal Energy Storage
  - Heat Delivery System
- Demonstration Facility

PROJECT NAME	Gen3 Gas Phase System Development and Demonstration: DE-EE0008368
FUNDING OPPORTUNITY	Generation 3 Concentrating Solar Power Systems (Gen3 CSP): DE-FOA-0001697
PRINCIPAL INVESTIGATOR	Shaun D. Sullivan
LEAD ORGANIZATION	Brayton Energy
PROJECT PARTNERS	NREL, Brightsource, Burns & McDonnell, DLR, Echogen, Edisun Microgrids, EPRI, SolarDynamics, SolarTAC, SOLEX, Southwest Solar Technology
PROJECT DURATION	2 years (Phases 1 and 2)
PROJECT BUDGET	$ 7,570,647

System Overview



Program Structure

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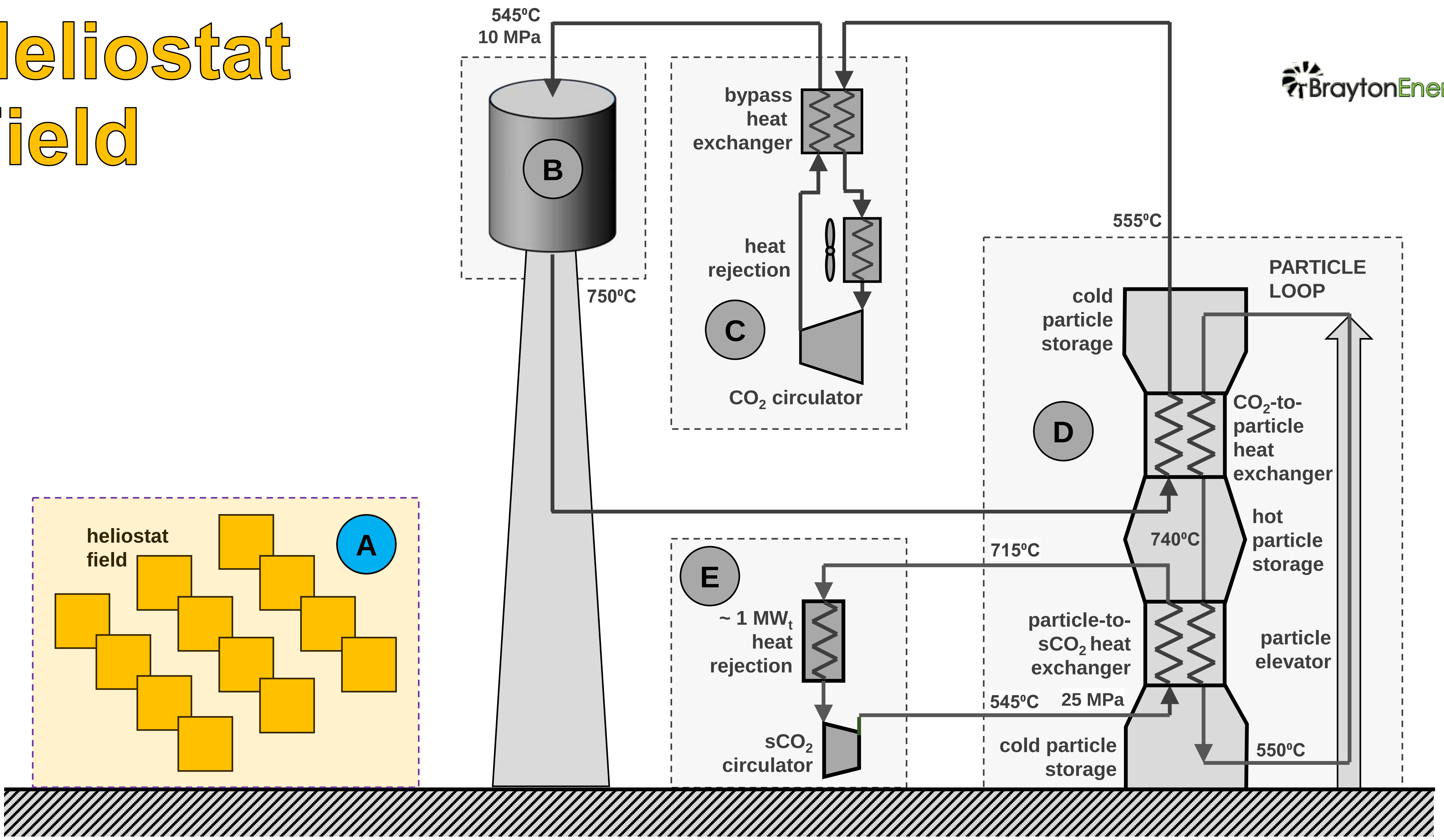
- **Phase 1**
  - Optimized commercial-scale system design
  - Demonstration-scale design
    - Incorporates commercial-scale componentry as much as possible
  - Subsystem subcomponent testing

- **Phase 2**
  - Ongoing performance modeling
  - Ongoing cost analysis modeling
  - Component and subsystem testing
  - Demonstration facility design
    - De-risk advanced technologies
    - Demonstrate integrated operation
    - Showcase facility for commercialization

PARAMETER	UNITS	COMMERCIAL	DEMO.
System Power	MW_e	50	n/a
RECEIVER			
Thermal Rating	MW_{th}	200	1.5
Pressure Drop	%	< 5% DP/P	< 5% DP/P
$\eta_{Annualized}$	%	≥ 90%	TBD
Fatigue Life	cycles	> 100,000	> 100,000
Operating Life	hrs	90,000	90,000
GAS PHASE LOOP			
Pressure Drop	%	< 5% DP/P	< 5% DP/P
Operating Power	%	< 2% of net power	TBD
THERMAL ENERGY STORAGE			
Storage Capacity	MWh_{th}	600	9
Storage Duration	hrs	up to 24 hours	up to 24 hours
$\eta_{energetic}$	%	99%	99%
$\eta_{exergetic}$	%	95%	95%
HEX Press. Drop	%	< 1% DP/P ea. side	< 1% DP/P ea. side
POWER BLOCK			
sCO_2 Pressure	MPa	25	25
sCO_2 Inlet Temp	C	545	545
sCO_2 Outlet Temp	C	715	715

Heliostat Field



Heliostat Field

Edisun Microgrids™

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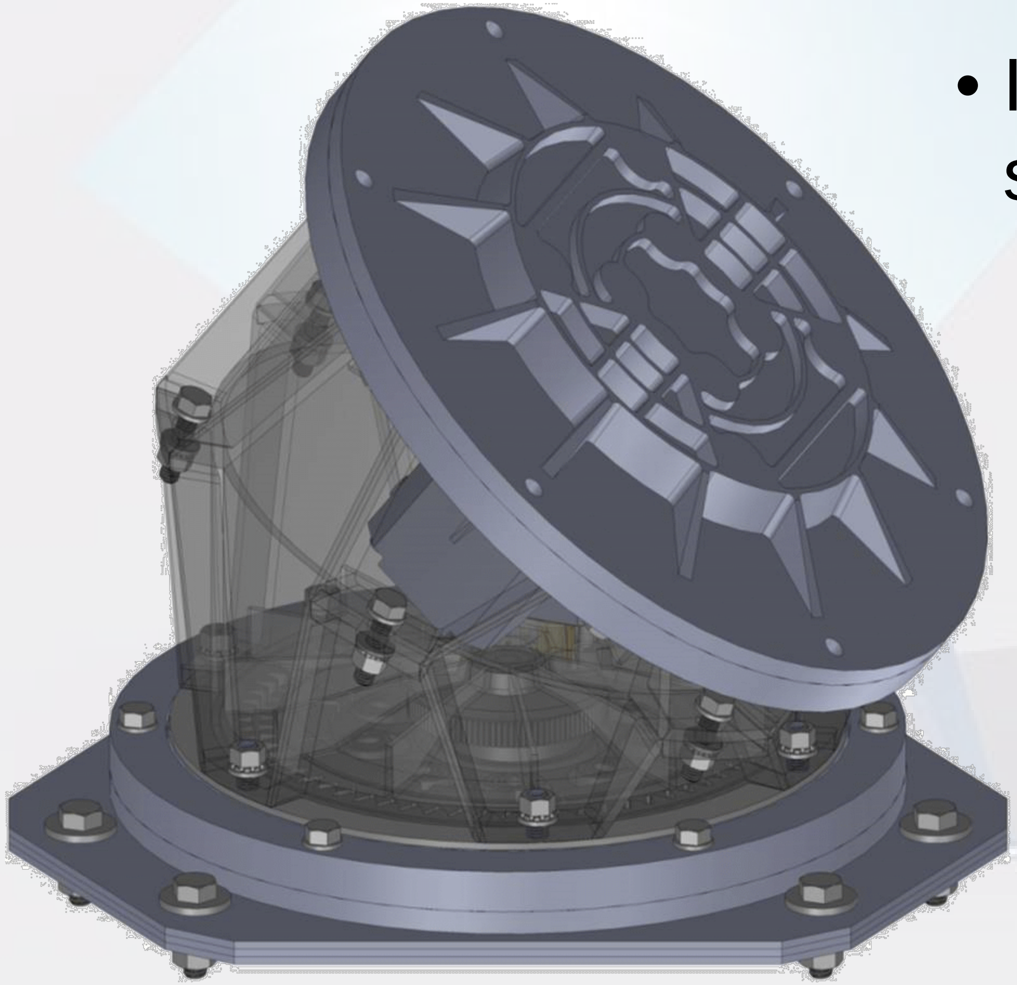
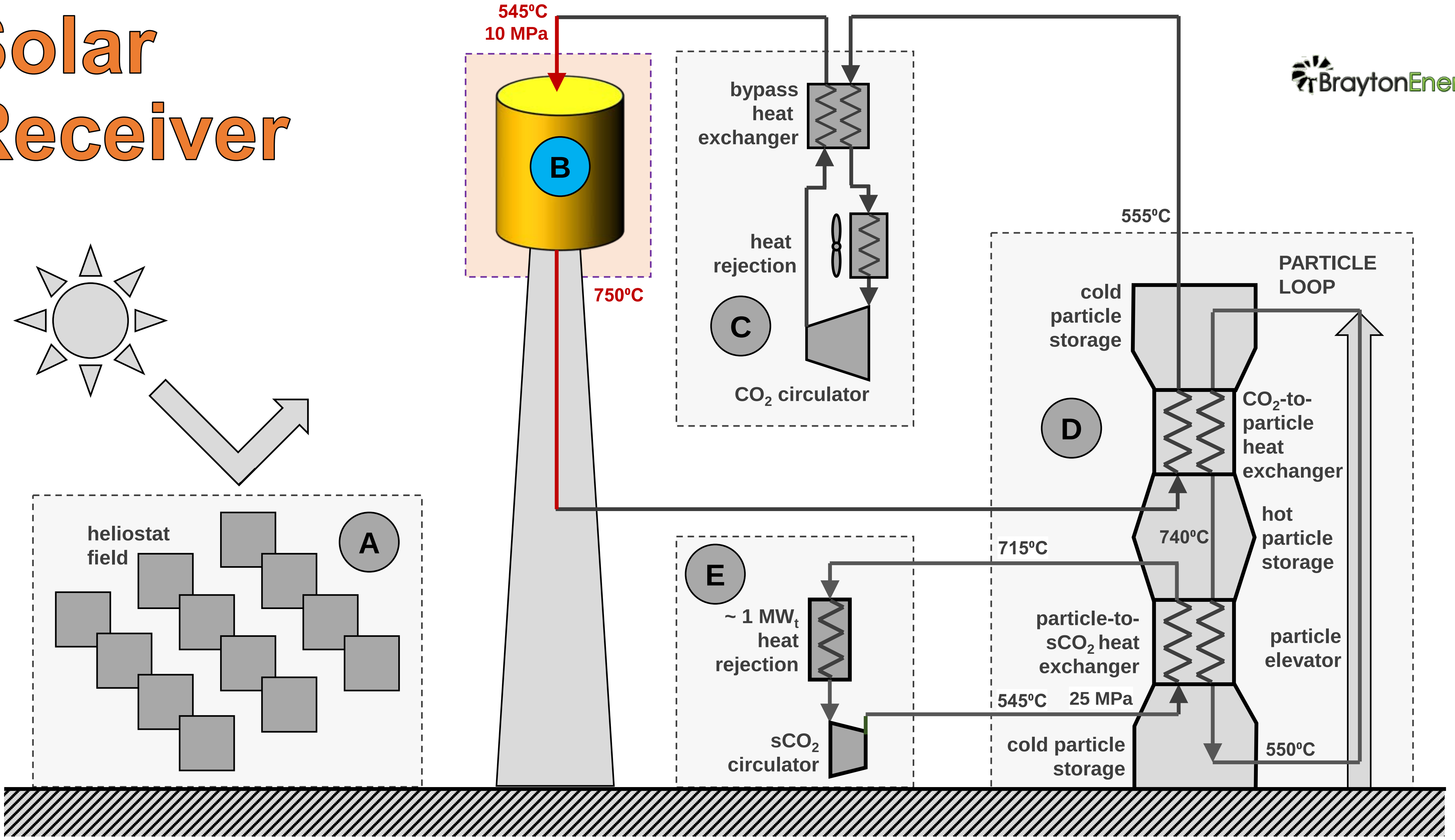
- Partner with ambitious US heliostat developer



- Incorporate and showcase emerging state-of-the-art heliostat technologies
  - wireless control
  - novel low-cost manufacturing
  - innovative calibration method

- Heliostat/controller supplier providing substantial in-kind field support to program’s test objectives.

Solar Receiver

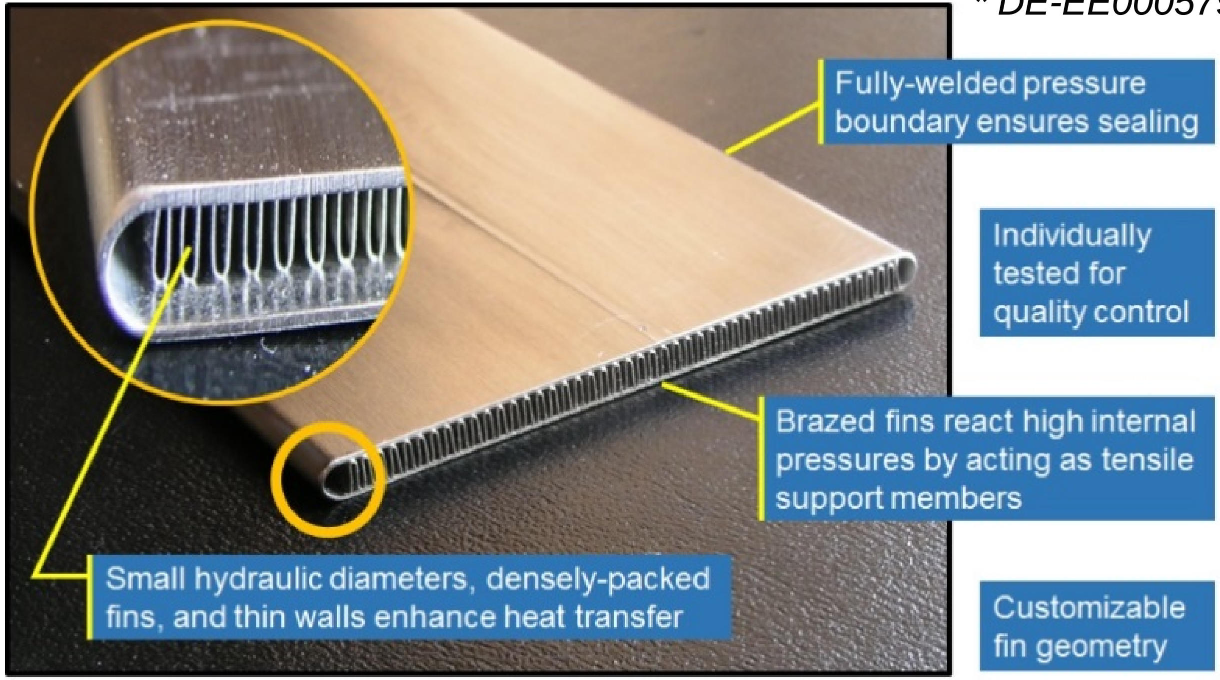


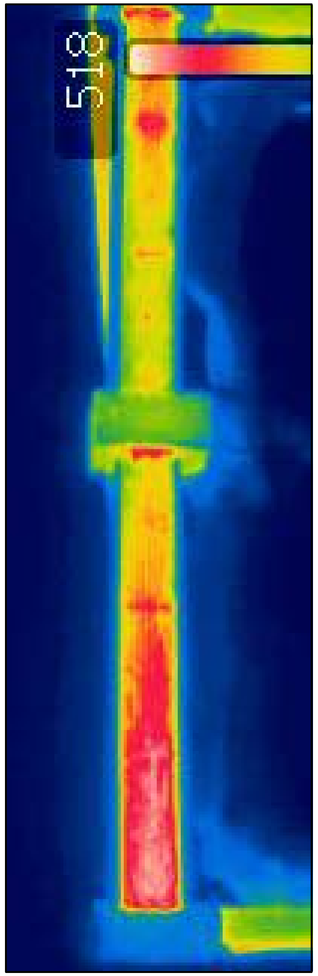
BraytonEnergy Solar Receiver

Powered by SunShot
U.S. Department of Energy

High-Efficiency Low-Cost Solar Receiver for use in a Supercritical CO_2 Recompression Cycle

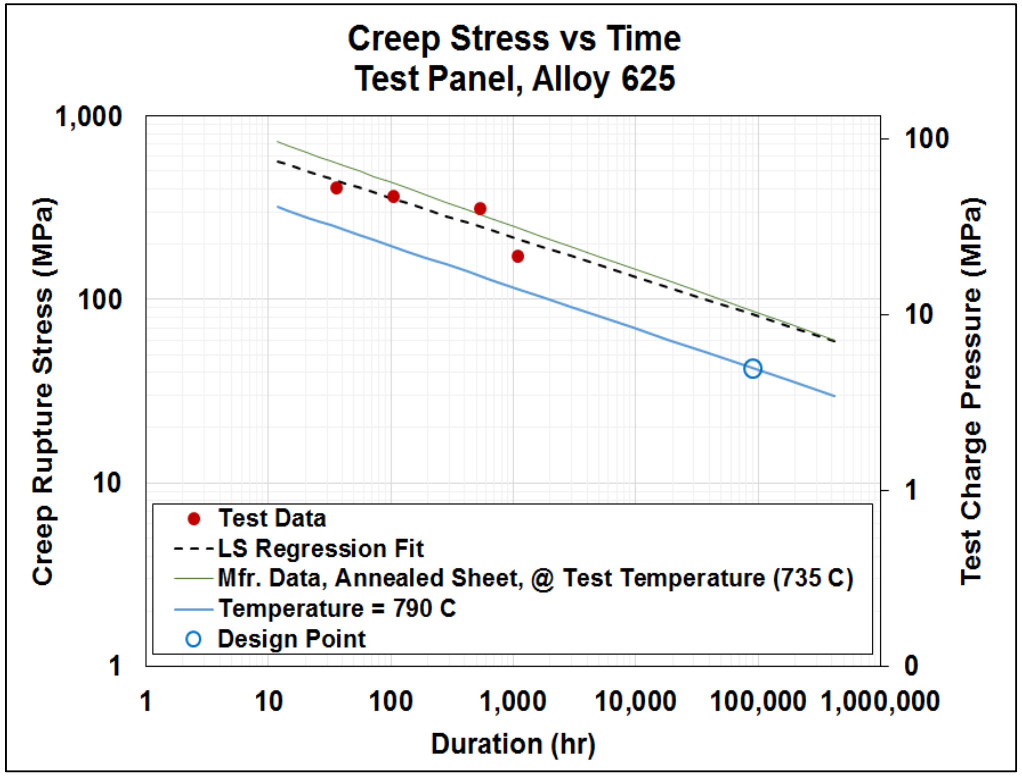
** DE-EE0005799*

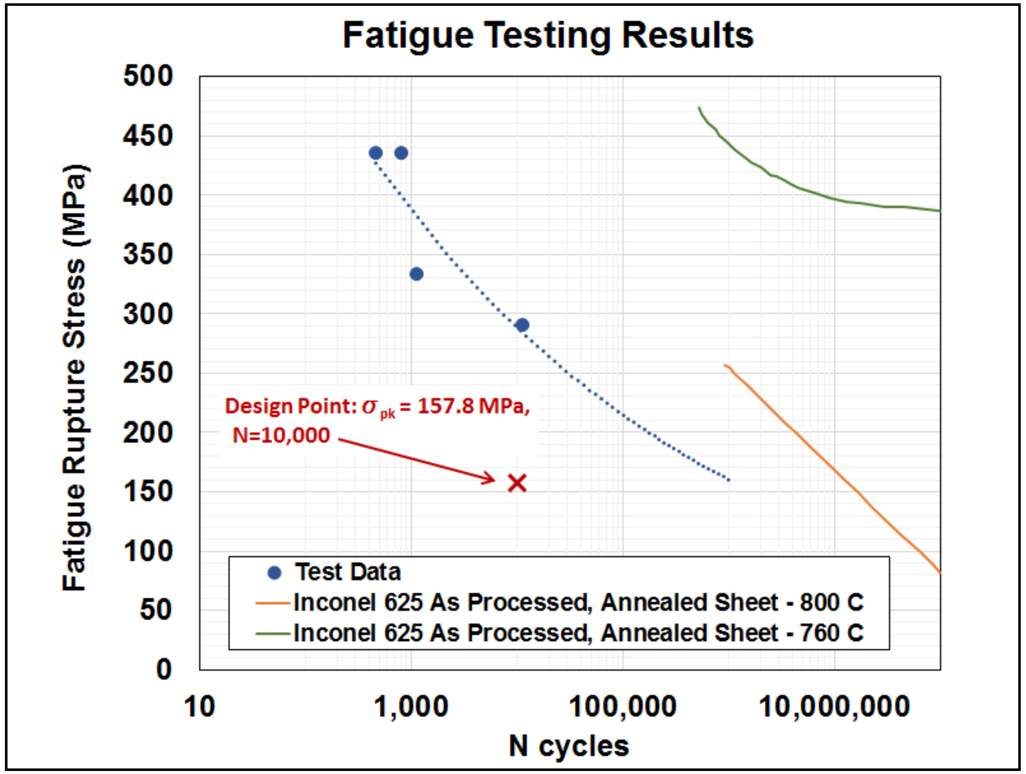




Absorber Cell Creep, Fatigue Testing

- All life testing performed with sCO_2 at 790 C





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Receiver Performance Summary

PERFORMANCE METRIC	SUNSHOT TARGET	CAVITY RECEIVER BRAYTON TARGET	CAVITY RECEIVER BRAYTON RESULTS[1]	EXTERNAL RECEIVER BRAYTON TARGET	EXTERNAL RECEIVER BRAYTON RESULTS
Receiver Creep Life	n/a	≥ 90,000 hours	60,000 hours	≥ 90,000 hours	90,000 hours
Receiver Fatigue Life	≥ 10,000 cycles	≥ 10,000 cycles	≥ 100,000 cycles	≥ 10,000 cycles	≥ 100,000 cycles
Receiver Cost	≤ $150/kW$_{th}$	≤ $120/kW$_{th}$	$98/kW$_{th}$	≤ $150/kW$_{th}$	$124/kW$_{th}$
HTF Exit Temeprature	≥ 650 ^{o}C	≥ 750 ^{o}C	750 ^{o}C	715 ^{o}C	715 ^{o}C
Receiver Efficiency $\eta_{thermal}$	n/a	≥ 95%	94.9%	*(partner defined)*	90.62%
Receiver Efficiency $\eta_{annualized}$	≥ 90%	≥ 92%	93.1%	*(partner defined)*	88.36%
System Efficiency Gain	-	-	-	≥ 15.00%	30.30% (10.27 pts.)
Quartz Window Benefit	-	-	-	≥ 2.00%	6.1% (5.5 pts.)

[1] *Results as of Phase 2, and costs do not include tower; further improvements would be achieved by applying Phase 3 learnings*

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Process Development

Manufacturing Process Development for Lower-Cost Heat Exchangers in High-Temperature/Pressure Applications

* *DE-FE0024020*

- Joint program with NETL
- funded through the Office of Fossil Technology
- Developed and demonstrated manufacturing process improvements that enabled sCO_2 heat exchangers (775 ºC, 30 MPa) to be fabricated for $40/$kW_{th}$

Manufacturing Enhancements
Roll Forming/Post-Compaction
Metal Stamping
Melt Point Depressant Bonding
Cost Modelling

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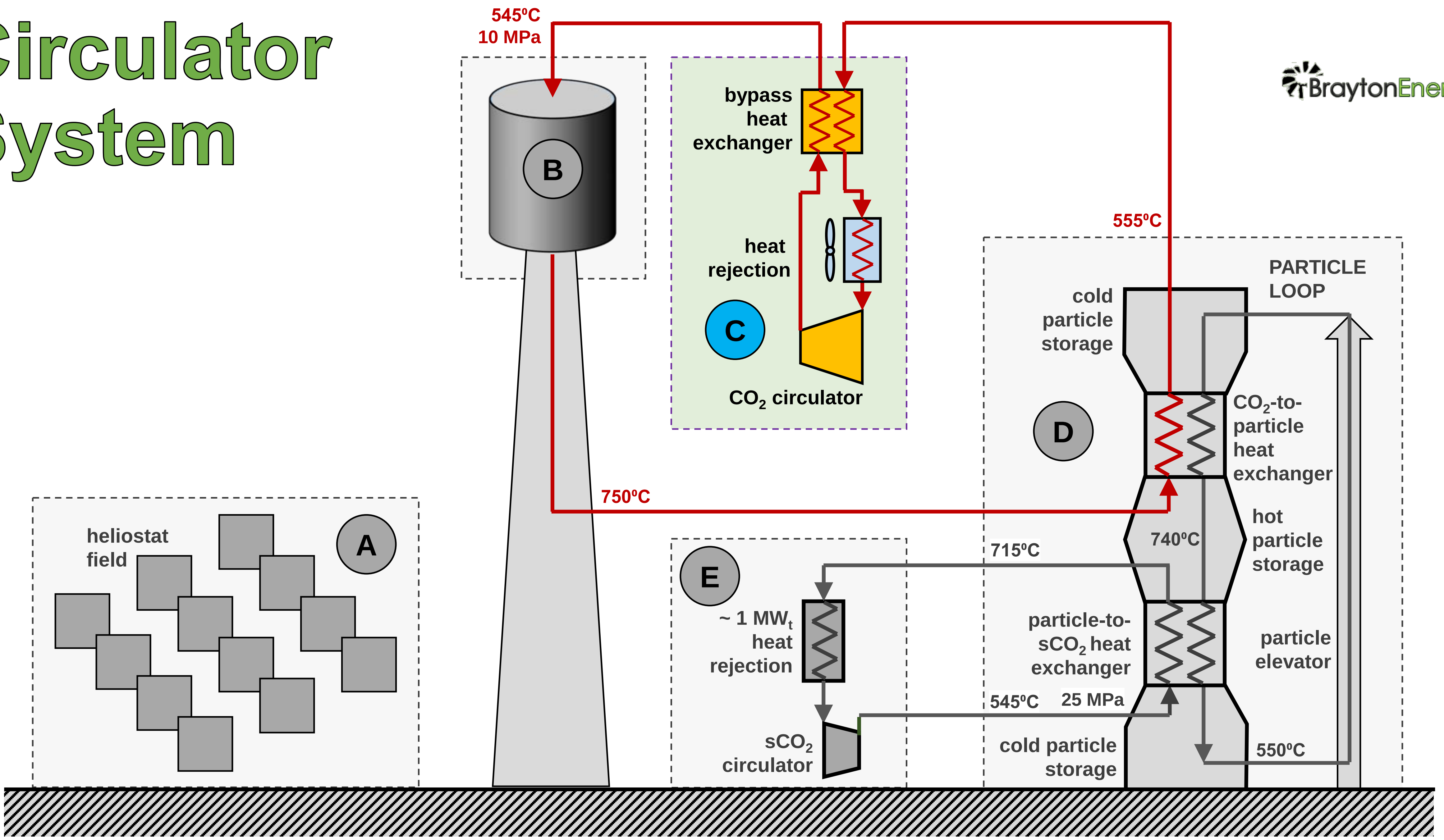
Circulator System



Circulator System

- Use an intermediate heat transfer fluid to deliver heat from the receiver to the thermal energy storage system
  - + Superior controls flexibility
  - + Thermal isolation of receiver
  - + Leverage proven receiver technology
  - - Receiver heat transfer
  - - Pumping parasitic
  - - Piping costs

- First developed for APOLLO* project:

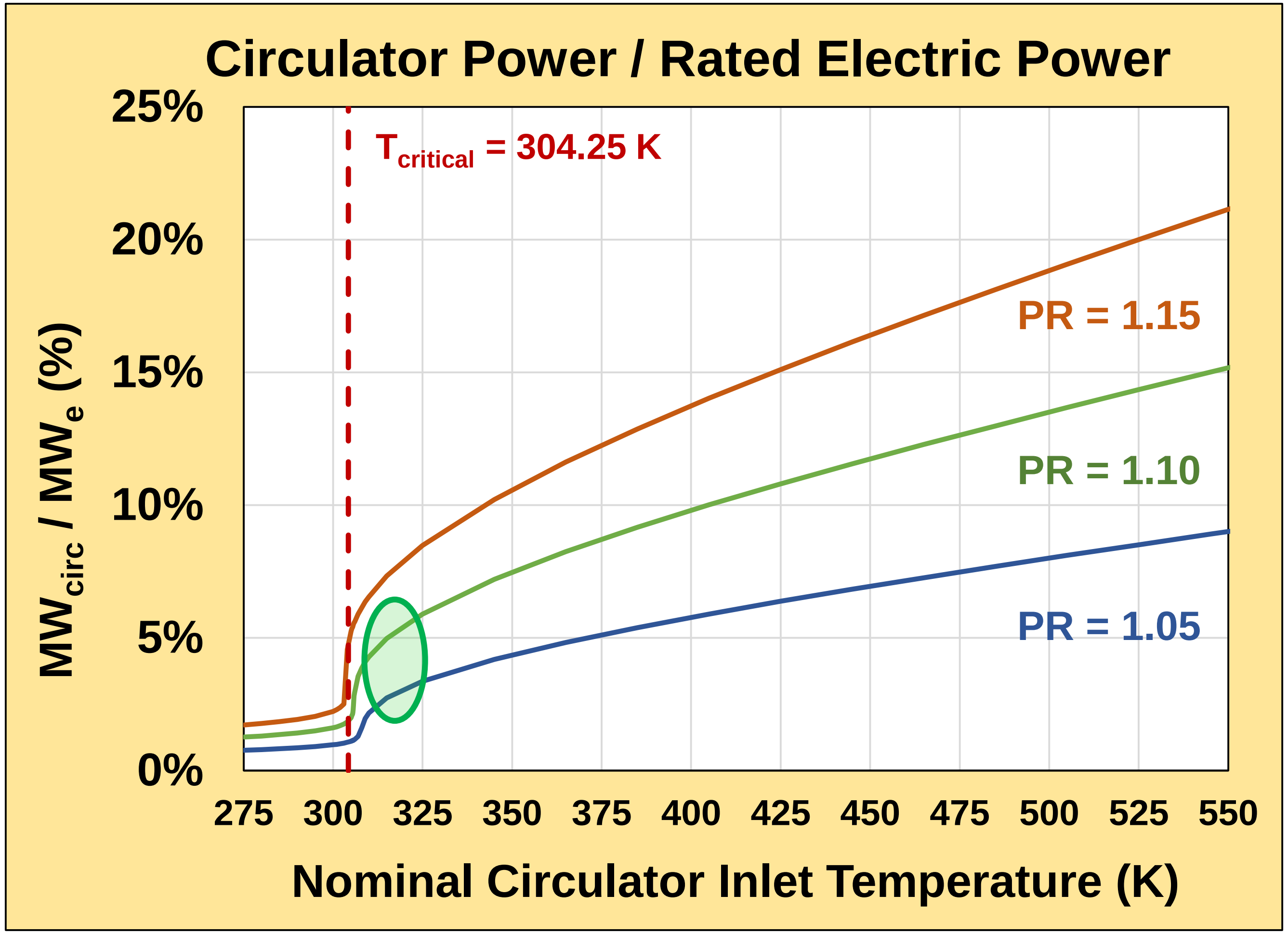
Solar Receiver with Integrated Thermal Energy Storage for a Supercritical Carbon Dioxide Power Cycle

Powered by SunShot
U.S. Department of Energy

<u>A</u>dvanced <u>P</u>rojects <u>O</u>ffering <u>L</u>ow-<u>L</u>COE <u>O</u>pportunities, DE-EE0001186

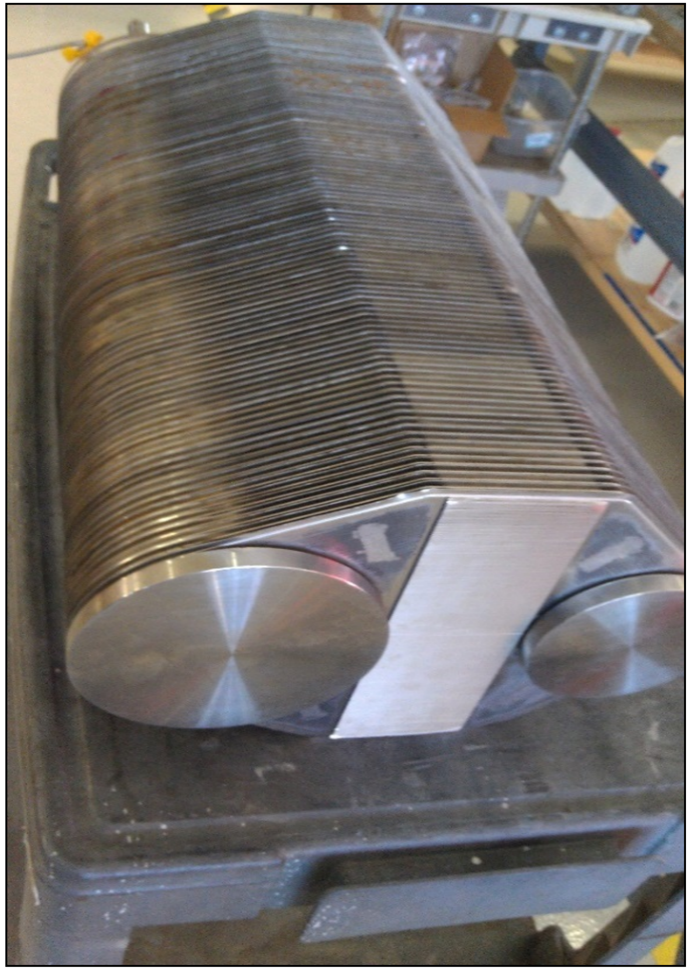
Circulator Power

- Use CO_2 and leverage the same supercritical properties that benefit the sCO_2 power cycle to achieve *low pumping power*

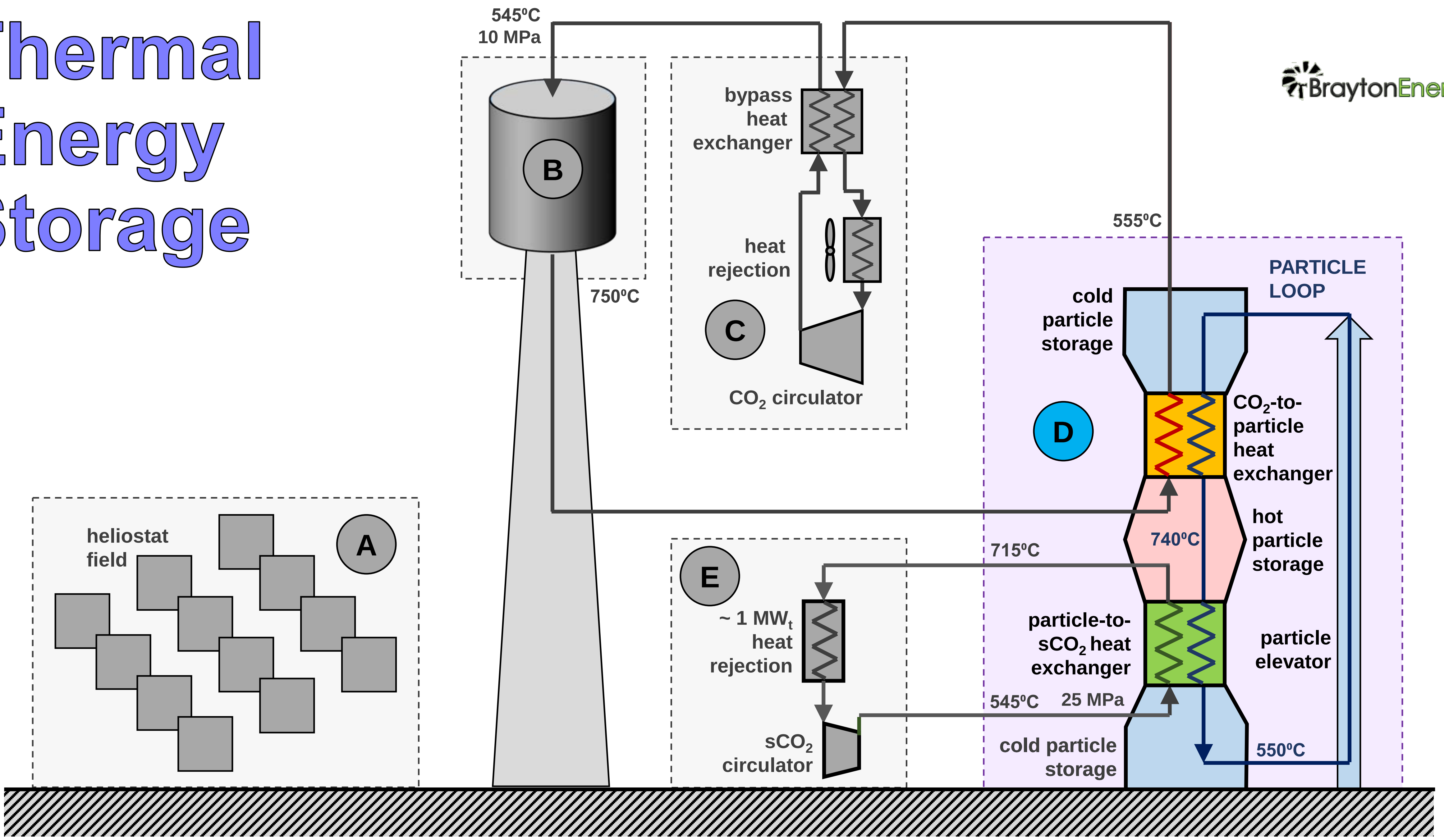


Circulator Heat Exchangers

Plate/fin heat exchanger designs derived from more than three decades of gas turbine recuperator design, manufacturing and testing.



Thermal Energy Storage



Thermal Energy Storage

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- Gas phase system is agnostic to the coupled TES technology:
  - Brayton and other team members are currently engaged in TES projects developing thermochemical, phase change, and sensible energy storage
  - Critical program goal is to continue monitoring the development of alternative TES systems to:
    - Determine if any emerging systems surpass a critical readiness threshold for incorporation into the Gas Phase system and Phase 3 demonstration facility
    - Design a demonstration facility that might enable the downstream testing of a promising alternative technology

Sensible storage has been identified as the lowest-risk near-term option for initial GEN3 design/development work

Baseline TES Design

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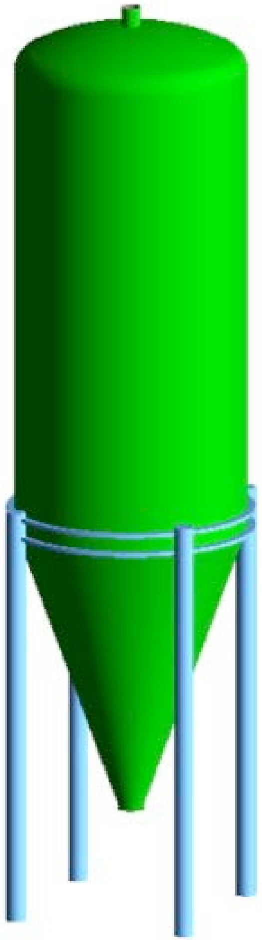
- NREL is leading the TES subsystem design, which in the baseline design consists of:
    0) Solid particle media
    1) “Cold” particle storage bin (550 C)
    2) Gas-to-particle (charging) heat exchanger
    3) Hot particle storage bin (750 C)
    4) Particle-to-sCO2 (discharging) heat exchanger
    5) Particle bucket lift to return cold particles to (1)
    6) Insulation, insulation, insulation

- Also evaluating:
    - alternative high-reliability flowing bed configurations with dramatically reduced operating power
    - static bed configurations



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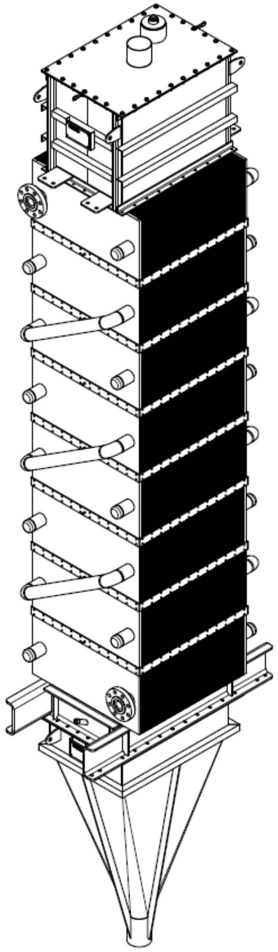

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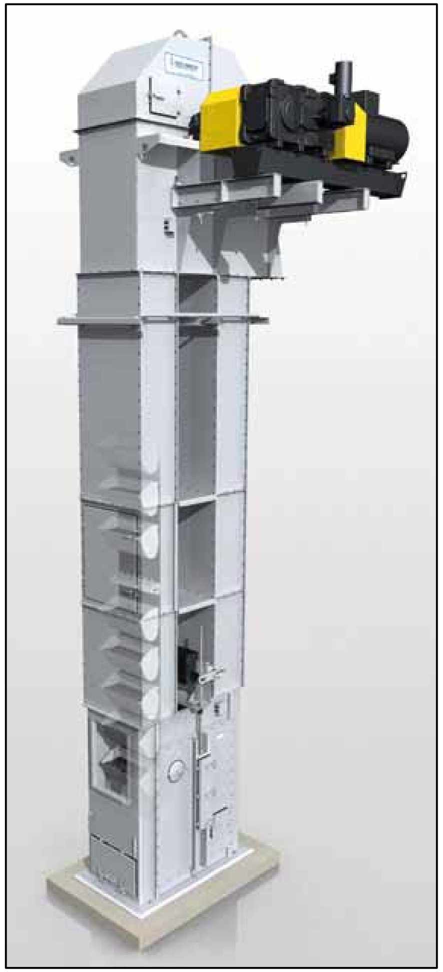

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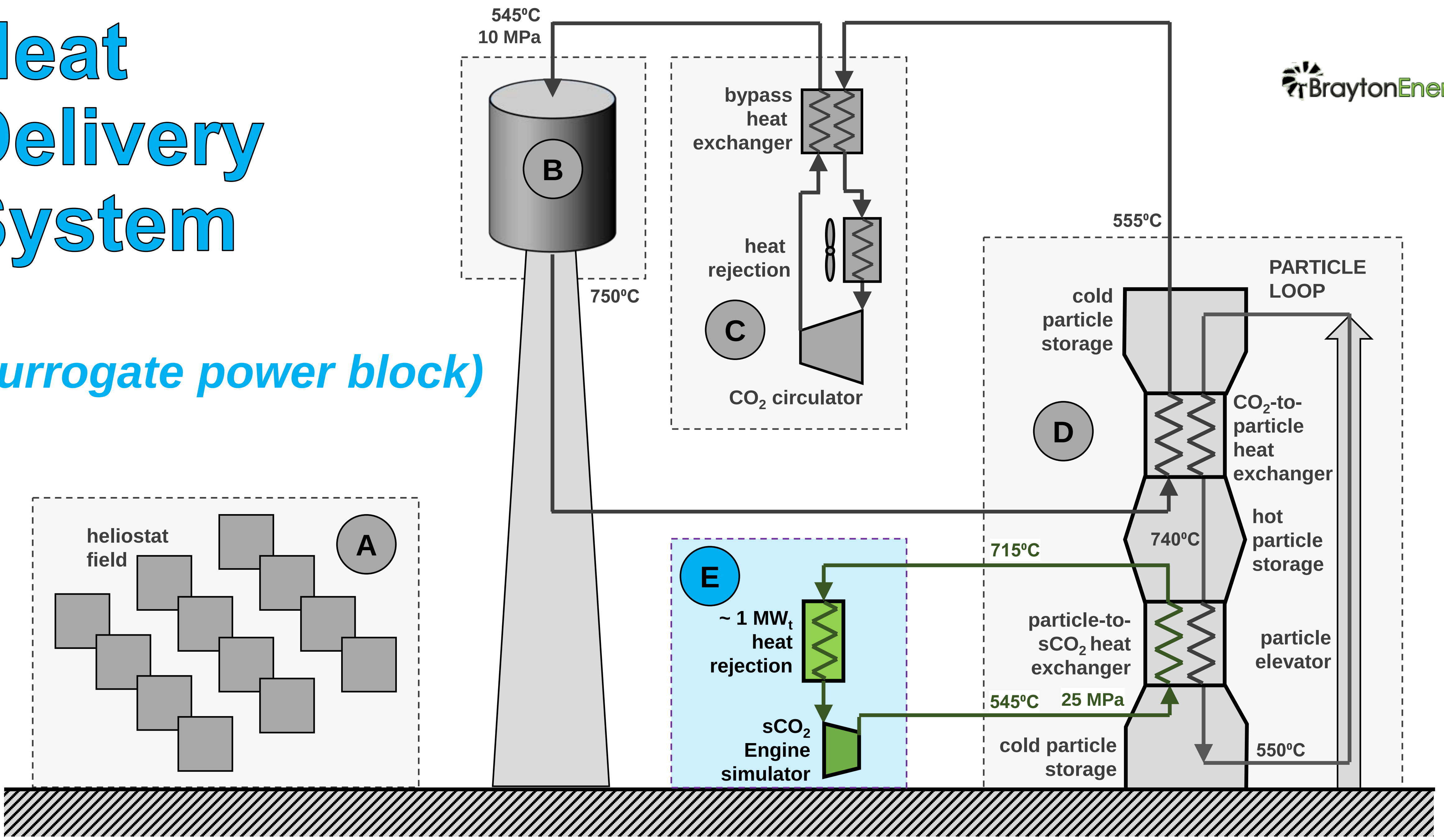
Additional TES Details

- Concept employs flowing packed-bed particle heat exchanger technology for particle-to-gas heat transfer
  - Dense granular flow over an array of parallel plates
  - Narrow channels in a shell-and-plate configuration enable high heat transfer coefficients (up to 200 W/m^2-K) in a compact geometry
  - Program targets 1.5 MW_{th}, approach temperatures of 20°C or less, fluid pressure drop less than 1%

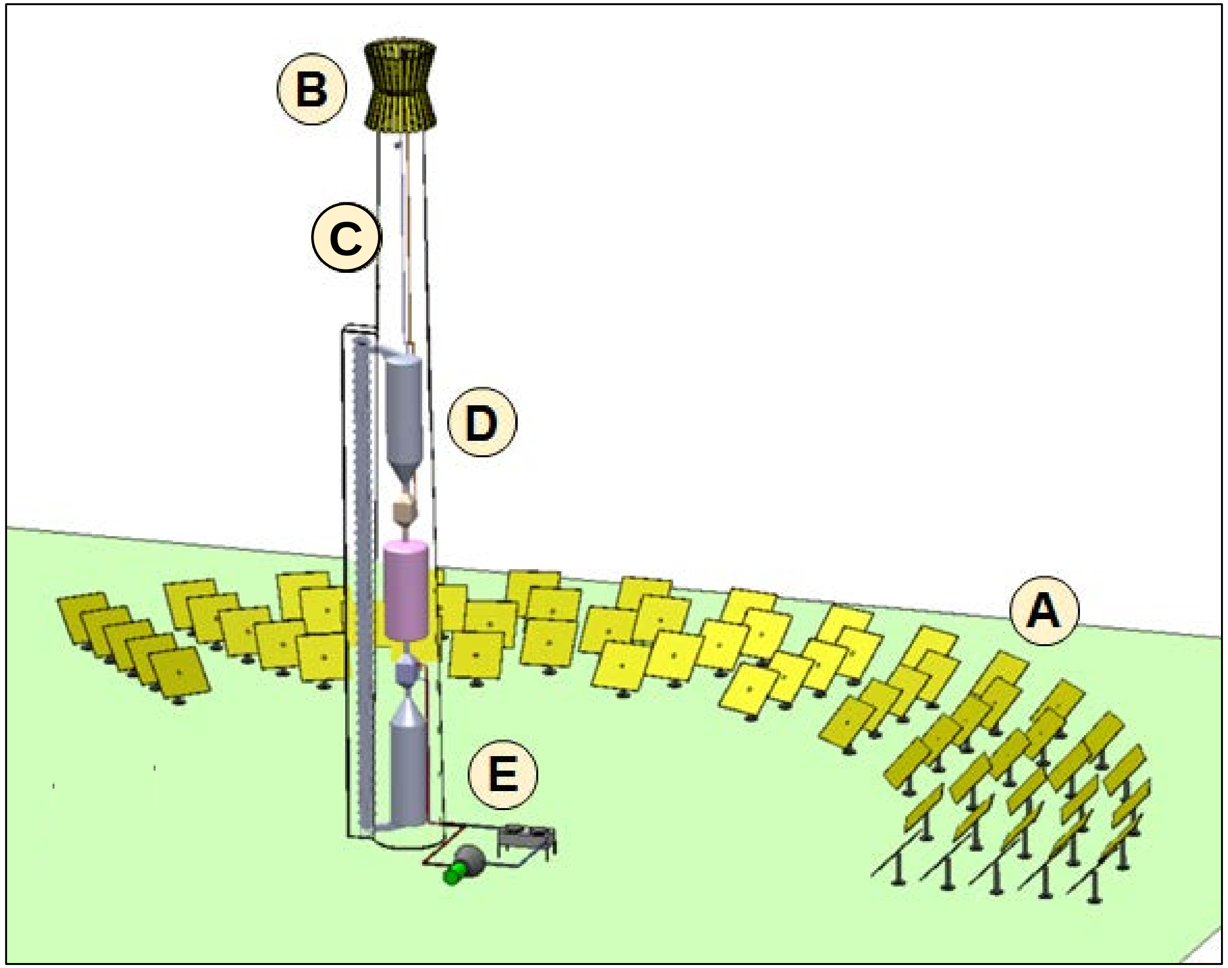
- Commercially available bucket elevators can be used up to temperatures of 600°C, with an operating parasitic approximately 1% of cycle gross power

Heat Delivery System

(surrogate power block)



Demonstration Facility



A. 1.5 MW_{th} Solar Field

B. Solar Receiver

- $\eta_{annualized} \geq 90\%$

C. CO_2 Gas Loop

- Operating power < 3% of Net Rating

D. Solid Particle TES

- 9 MWh_{th} Storage
- 24 hour deferral with $\eta_{Round\ Trip} = 99\%$

E. Waste Heat Rejection

- Surrogate for power block

Solar by B&M

Duke Energy Renewables
Panoche Valley Solar Project
240MW PV | Development

MidAmerican Energy
Topaz
550MW PV

Sempra US Gas & Power
Rosamond Solar
300MW PV

NRG Energy
Borrego 1
26MW PV

MidAmerican Energy
Solar Star I & II
580MW PV

NV Energy
Ft. Churchill Solar Project
20MW PV

Sempra US Gas & Power
Copper Mountain I, II, & III
48MW PV | 150MW PV
250MW PV

NRG Energy
Ivanpah Units 1-3
392MW | Solar Power | Tower

Sempra US Gas & Power
El Dorado
10MW PV

NV Energy
Spectrum Solar Facility
30MW PV

NRG Energy
Community Solar 1
6MW PV

Sempra US Gas & Power
Mesquite Solar I
170MW PV

Tucson Electric Power
H. Wilson Sundt
Generating Station
5MW | Concentrated Solar

Colorado Springs Utilities
US Air Force Academy
6MW PV

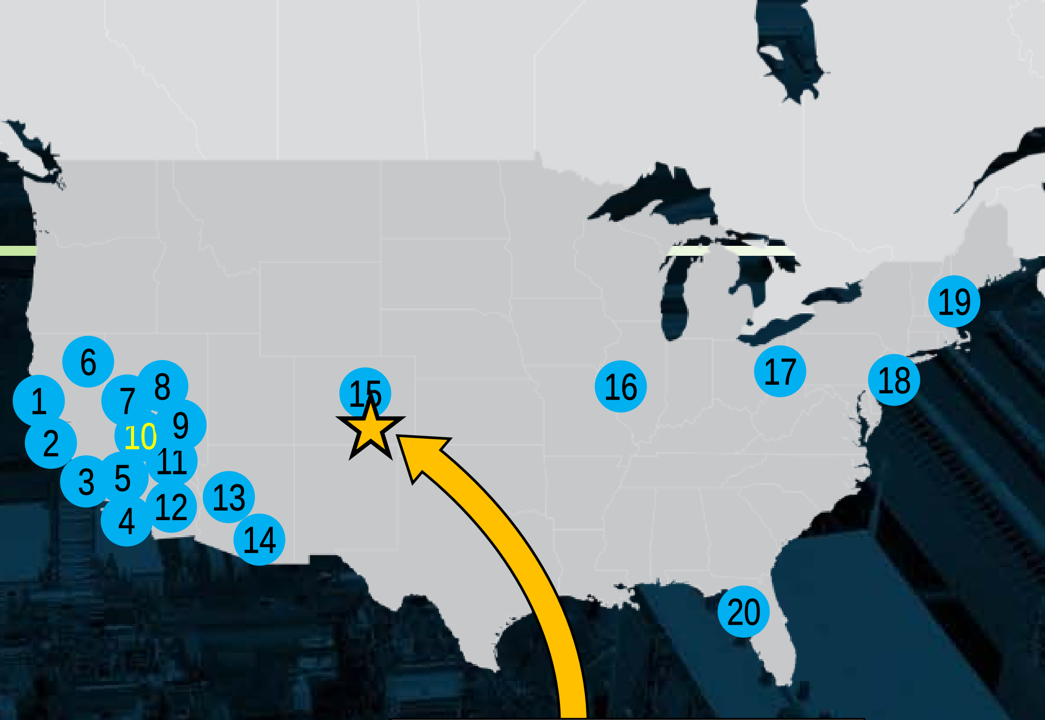
Ameren O'Fallon
Renewable Energy Center
4.5MW PV

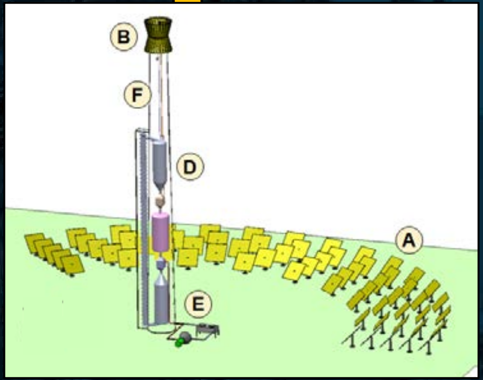
Agile Energy Turning Point
50MW PV

NRCO
Herbert Farm Solar Power Plant
5.5MW PV

GDF Suez Northfield Mountain
2MW PV
Mount Tom
5MW PV | 300 MW CC

TECO
Big Bend Solar EPC
20MW AC PV





Brayton Energy et. al.
Gen3 Demonstration Facility
1.5MW Advanced CSP

SolarTAC
Technology Acceleration Center

SolarTAC
Technology Acceleration Center

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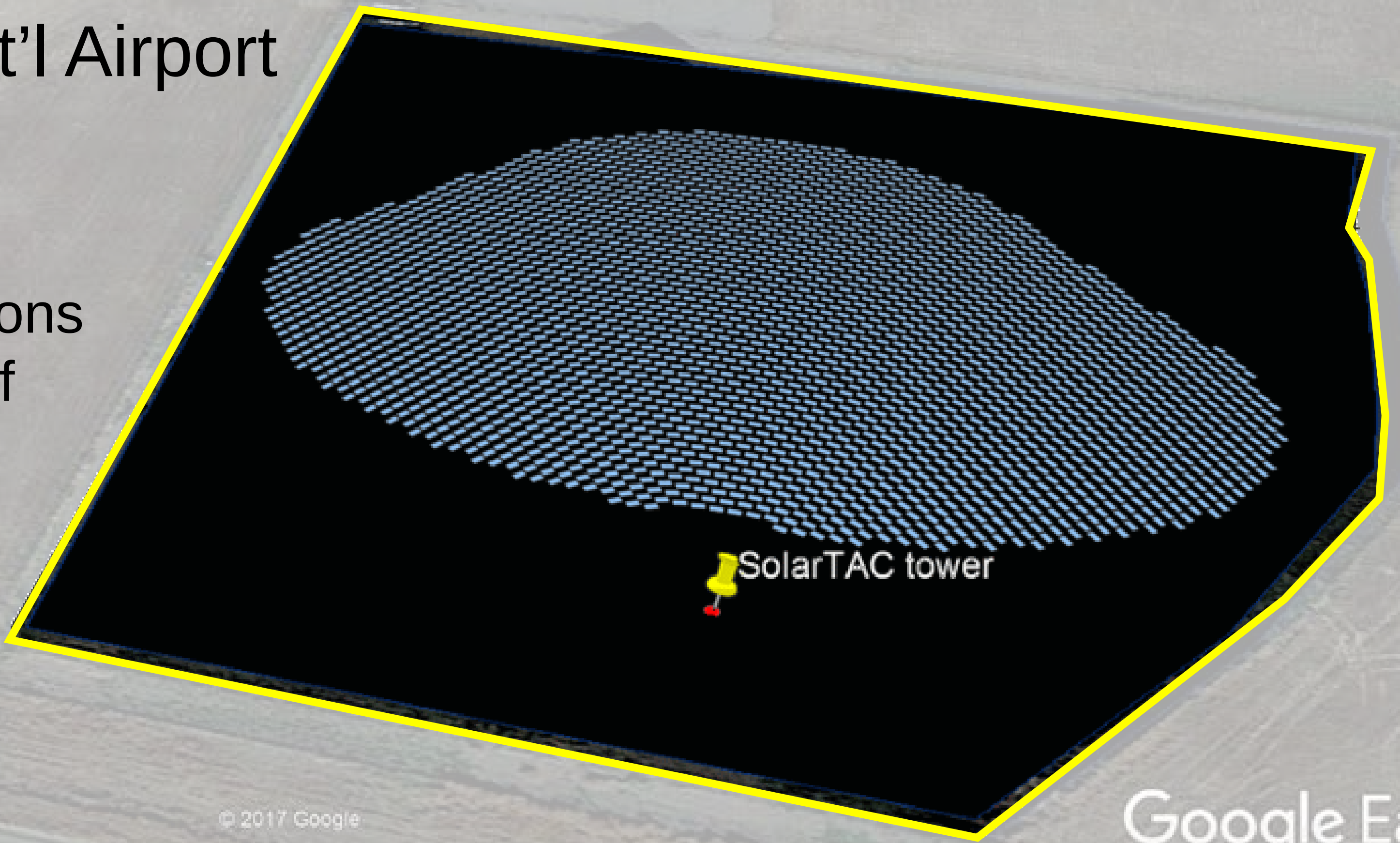
- With 74 acres, SolarTAC is the largest test facility for solar technologies in the United States
- Located near Denver Int'l Airport in Aurora, Colorado
    - flat, graded topography
    - excellent insolation conditions with more than 300 days of sunshine each year
    - access to grid interconnections.
    - all utilities and support services



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Thank You